Accelerator Preparations for Muon g-2 Experiment at Fermilab

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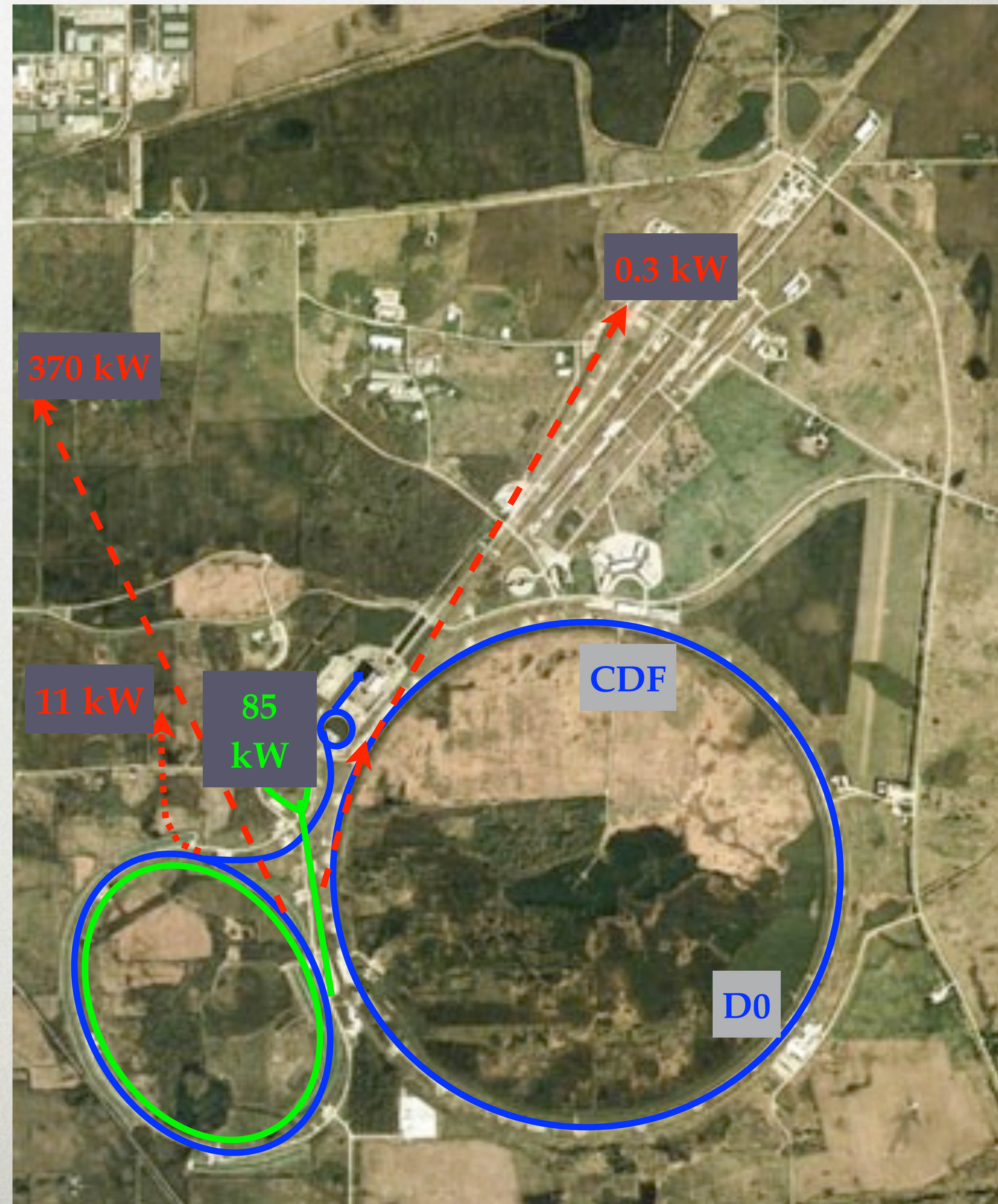
Outline:

- 8 GeV Proton Economics at Fermilab
- Proton Transport and Bunch Formation
- Targeting and Pion Collection
- Muon Transport to Storage Ring

Run II Operation

- Daily Operation
  - Set up p-pbar store in Tevatron, ...
  - Produce more antiprotons, and drive the **neutrino** program
    - time line governed by 1/15 s Booster cycle
  - 11 Booster pulses to MI every 2.2 s
    - 9 for NuMI
    - 2 for pbar production
  - Off-load pbars to Recycler ~every hour
  - Spare pulses (~4) to miniBooNE
  - 1 pulse to SY120 occasionally...



Post Run II

- Following Tevatron Run II...

to Minnesota:
MINOS, NOvA

to South Dakota:
LBNE

- On-going program of long baseline neutrino experiments

Post Run II

- NOνA is major program for Main Injector beam -- up to 700 kW
- MicroBooNE, also approved, will utilize existing beam line used for miniBooNE
- In addition, following Collider Operation, Antiproton Source becomes available for other uses
    - Already proposed for use in Muon-to-Electron Conversion Experiment (**Mu2e**)
    - Time between Run II ending and **Mu2e** start-up provides for early mounting of **New g-2** experiment

NOvA / ANU and Proton Plan

- To meet the needs of the neutrino program utilizing the Main Injector, FNAL successfully completed the Proton Plan project and is following through with the Accelerator and NuMI Upgrades project (ANU)
  - Proton Plan -- updated hardware in the Booster synchrotron to allow higher beam repetition rate -- up to 9 Hz average rate
  - ANU -- upgrading Main Injector and Recycler to allow for higher beam throughput in both synchrotrons -- brings MI to 700 kW beam power

Proton Throughput

- The 8 GeV Booster magnet system operates at a 15 Hz rate; however, beam throughput presently limited to ave. of ~9.5 Hz due to RF system components; runs at ~7 Hz for reliability during Run II; continuing improvements toward full 15 Hz capability.
- For today's Antiproton production and NuMI/MINOS neutrino experiment, only about 5 Hz required from Booster; spare cycles presently used to provide beam to miniBooNE (1-2 Hz, ave.).
- The NOvA neutrino experiment requires beam from Booster at average rate of about 9 Hz (hence, the Proton Plan upgrades).
- Thus, ~9 Hz for NOvA, and up to as much as ~6 Hz available for other programs at 8.9 GeV/c.

Proton Throughput

- With present Booster running conditions, at ~4 Tp/pulse,
  - ~ 1 Hz <==> 4 Tp/s <==> ~0.8×10^{20} POT/yr
  - Program requests are ~18×10^{20} POT over about 6-7 years
    - thus, need an average rate of ~3^+ Hz, beyond the 9 Hz for NOvA

Experiment	Total Beam Request
MicroBooNE	6.7×10^{20} POT
$g-2$	4.0×10^{20} POT
Mu2e	7.2×10^{20} POT

- While a 15 Hz Booster is ultimate goal, the extra 6 Hz this would provide is twice that which is needed to meet the goals of these three requests.

Booster 8 GeV Program

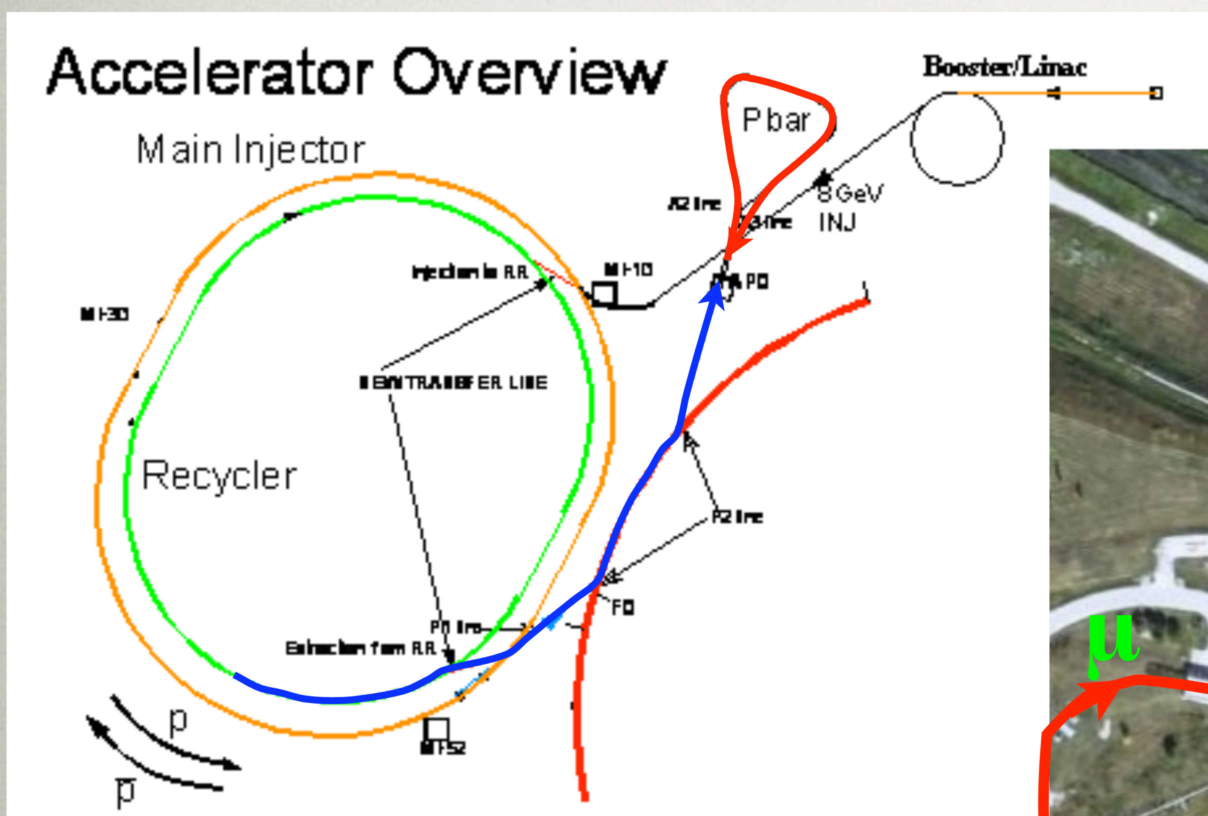
- MicroBooNE takes beam directly from Booster through its own line
- New g-2 experiment uses antiproton rings as a pion decay channel, tuned to momentum of 3.1 GeV/c
- Mu2e will also use antiproton rings, tuned to 8.9 GeV/c
- These two experiments can share certain infrastructure and beam lines
- Switching between g-2 and Mu2e experiments is mutually beneficial, allowing these precision experiments to perform analysis and work on systematic errors
  - switch-time ~ 2-4 weeks, max.; maybe much less

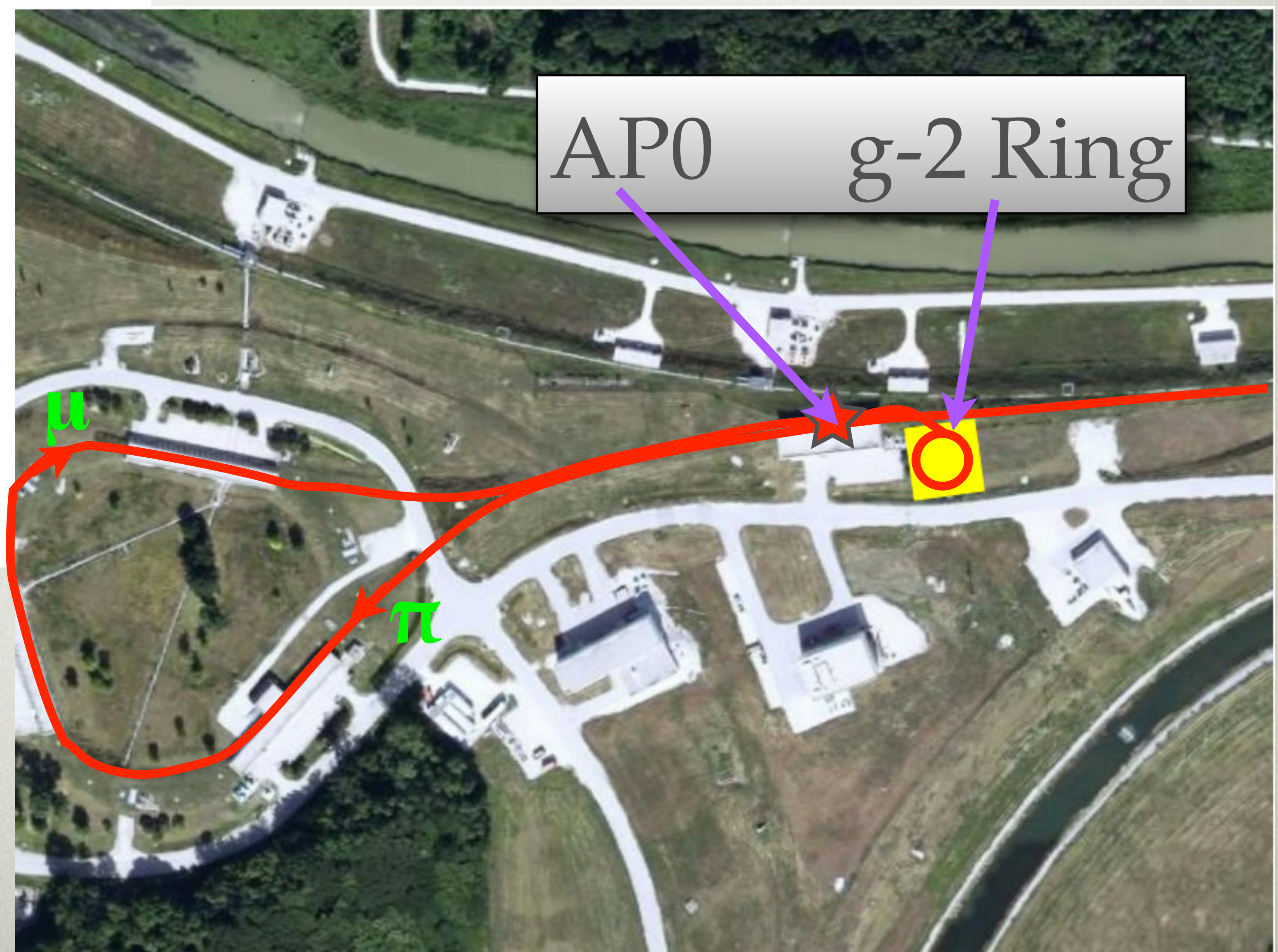
The g-2 Baseline Proposal

- New g-2 operates "per Booster cycle" (1/15th of sec.)
  - send Booster pulse to the Recycler
  - form into 4 bunches -- takes about 30 ms to perform
  - transfer one-at-a-time to g-2 Ring, every 12 ms; all occurs within one Booster cycle (details in back-up slides)
  - Note: bunches ~30 ns (rms) in length, ~ 10^{12} each
- Proposal is to deliver beam to target on 6 Booster cycles, every NOvA cycle (1.333 s)
  - thus, average rate is 4.5 Hz -- *could* meet requested POT in 1 year, though requesting 2; thus, conservatism built in

g-2 Proposed Operational Scenario

- Target at AP0 target hall; use pbar rings as 1-pass "decay channel" for pions; accumulate muons in g-2 ring



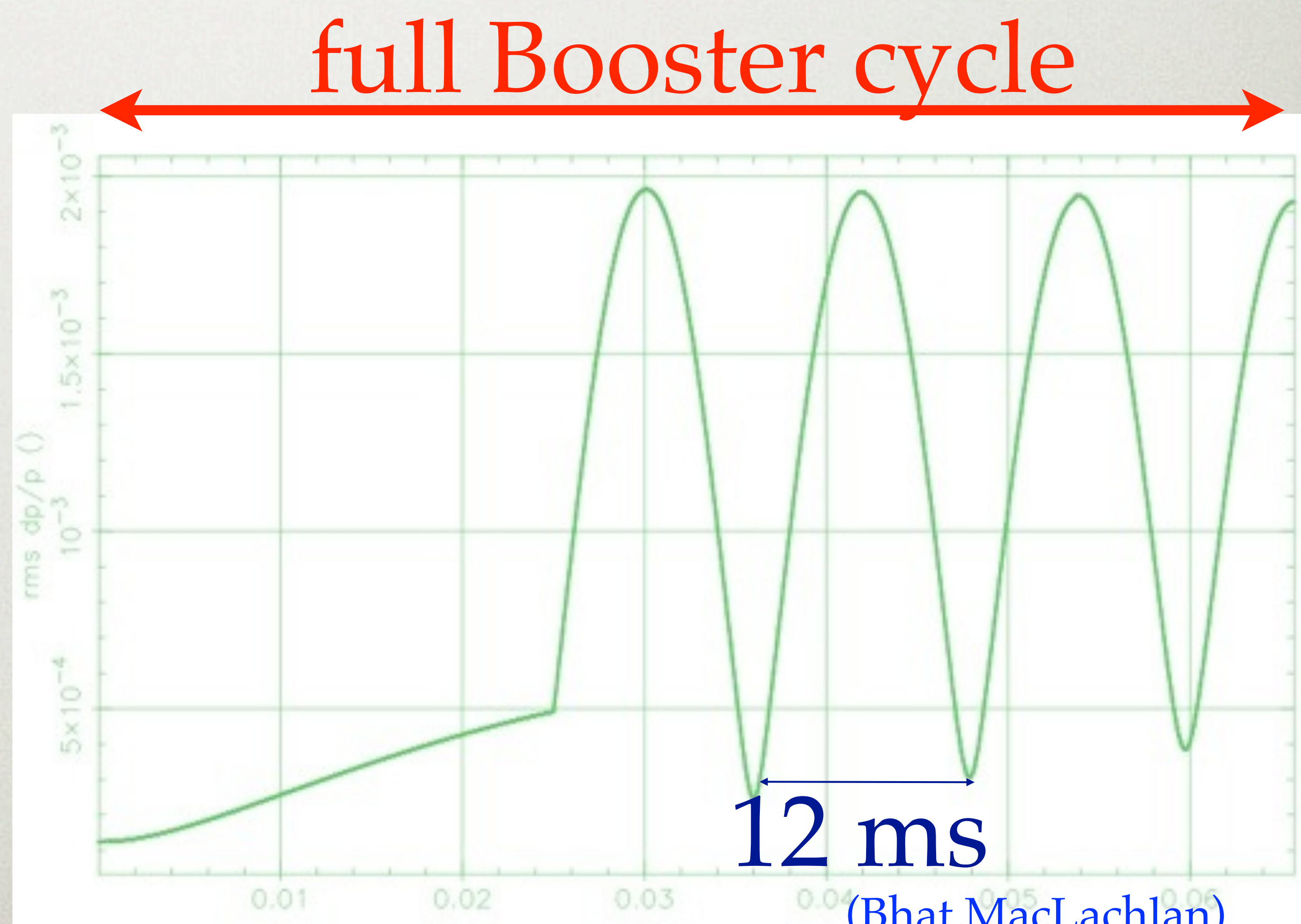


FNAL Plan--Booster to Recycler

- Use same transfer into the Recycler as NOvA
- Allow beam to circulate, and form into bunches, prepare for extraction

FNAL Plan--Recycler

- To control rate-dependent systematics, need to re-bunch each Booster batch into 4 bunches in the Recycler, 400 ns spacing
  - implies average rate of ~18 Hz into exp., compared to 4.5 Hz at BNL E821
- Need to move existing 2.5 and 5.0 MHz RF systems from MI to Recycler, possibly need to increase voltage by 10-30%
- Extract bunch every 12 ms



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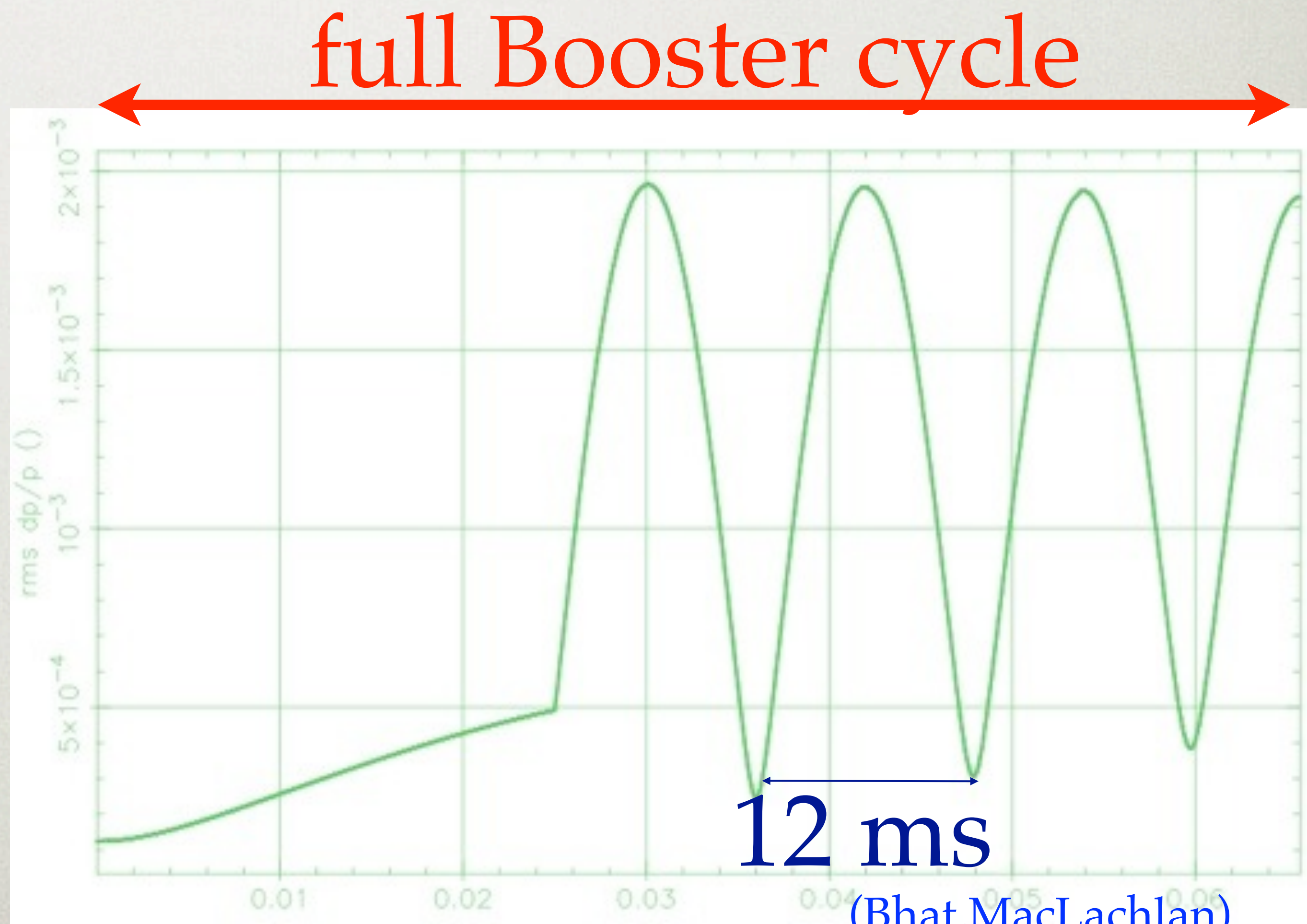
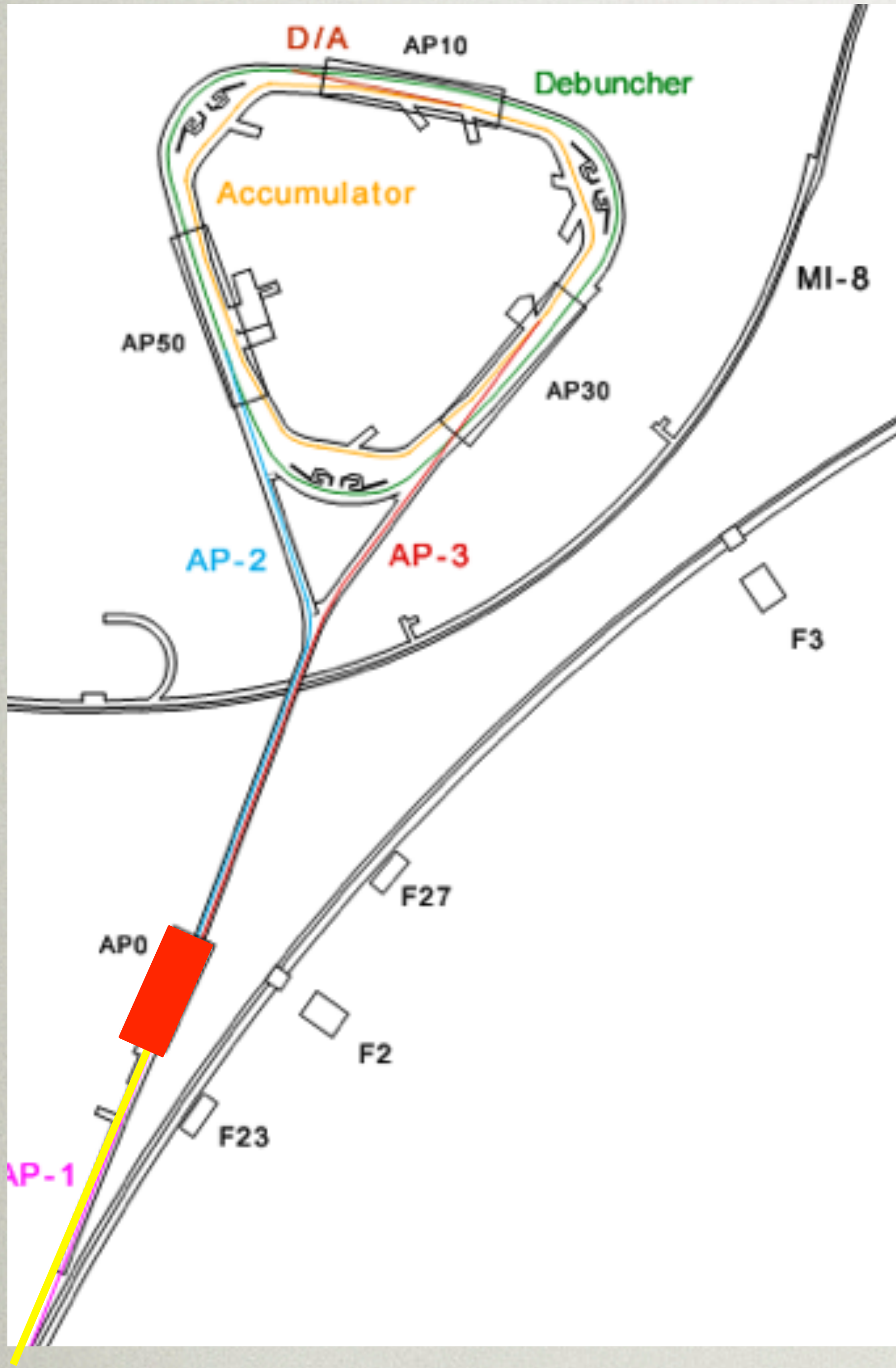


FNAL Plan--Extraction to AP1

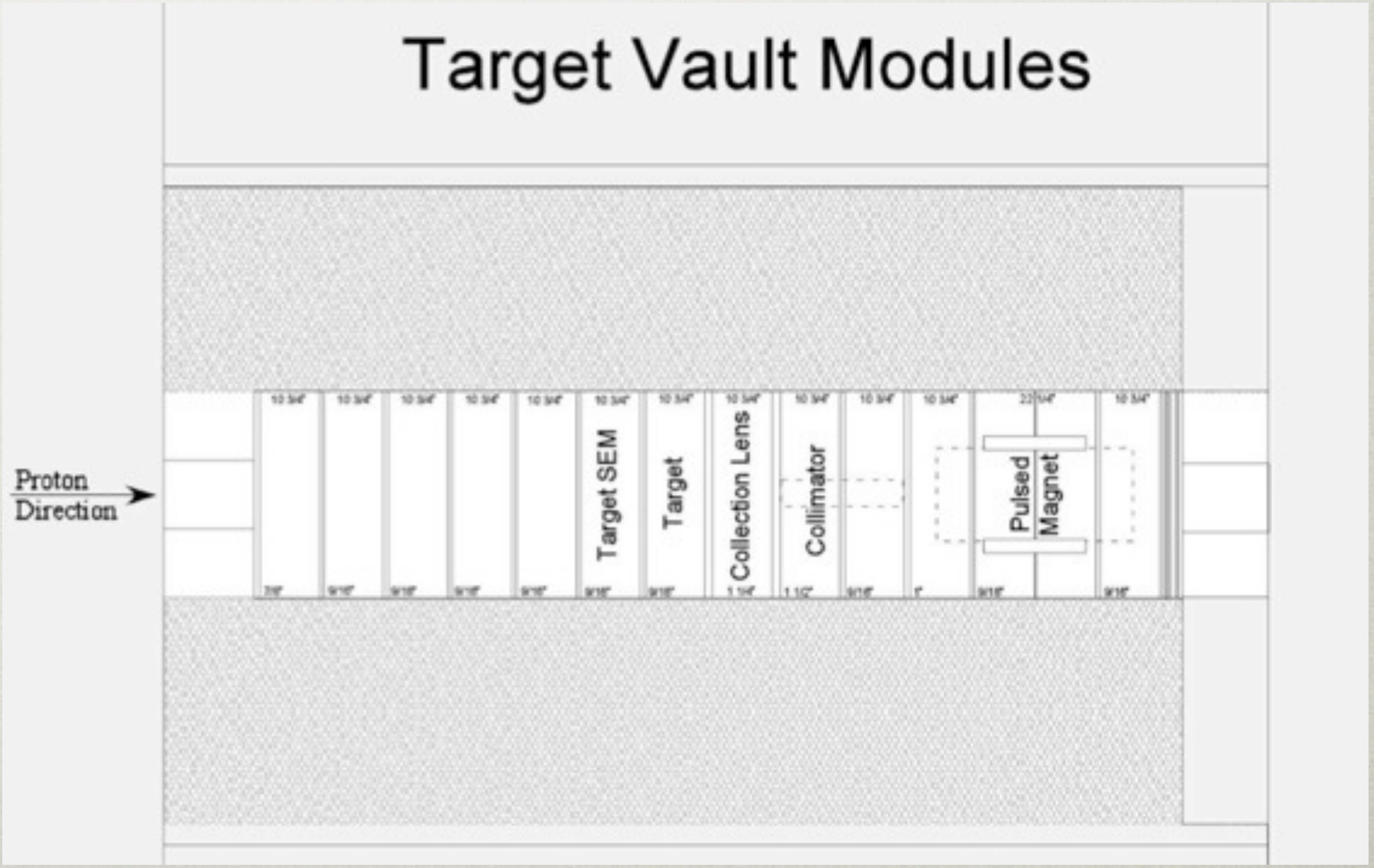
- Very similar to NOvA injection line
- Extraction hardware necessary, also, for Mu2e
- Connects Recycler to beam lines leading toward the 8 GeV storage rings
  - preliminary optics design exists, mechanical layout being drawn, tunnel interferences being checked
- Requires a kicker to eject bunch every 12 ms
  - Average rate of 18 Hz
  - Rise time 180 ns, flat top 50 ns, back down in 5 μs, ready to kick again in 12 ms
  - similar components to kicker required for Mu2e; should be able to share much of the hardware
- Remove today's aperture restrictions to handle the 25 kW, 8 GeV beam

FNAL Plan--AP0 Target Station

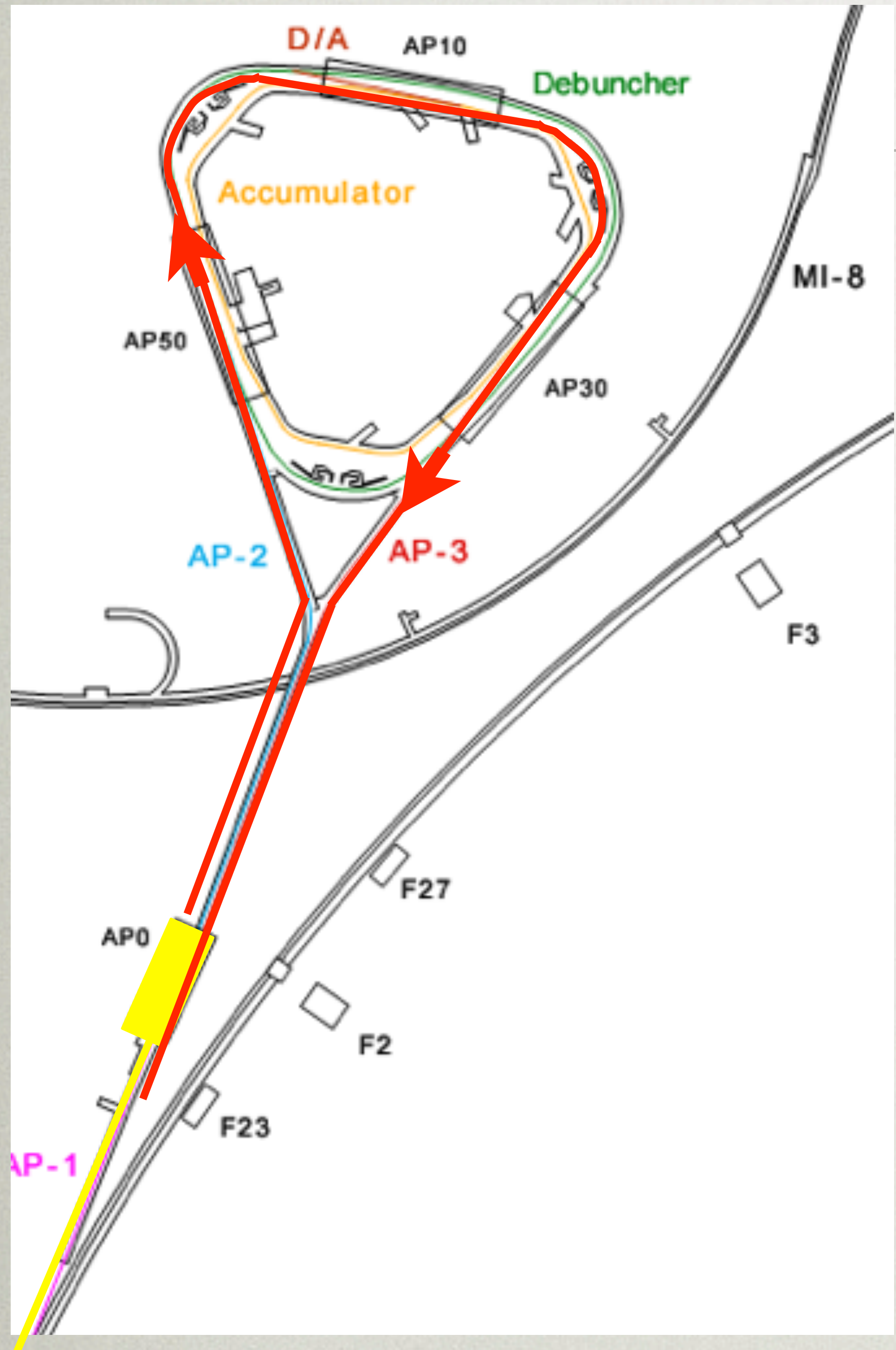


(Huhr, Leveling, Mokhov, Morgan, Nagaslaev, Striganov, Werkama, Wolff)

- Plan A: Use conventional rad-hard quads
  - Solution used in BNL E821
- Plan B: Re-use current target & Li lens (used for pbars)
  - Have to evaluate if Li lens can operate at higher rate with reduced current
- Also looking at a multi-turn, DC PMAG design

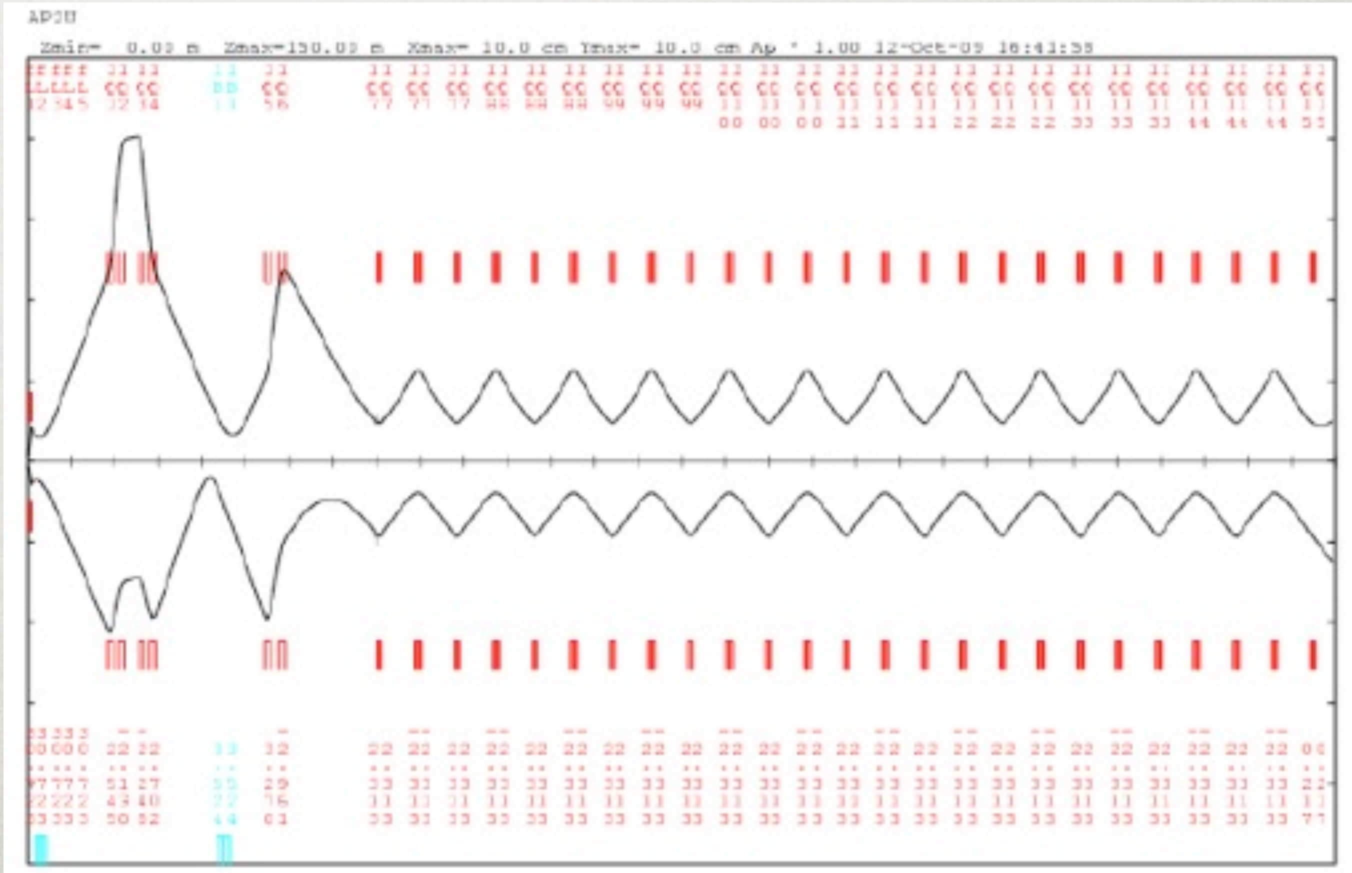


FNAL Plan--Pion decay line

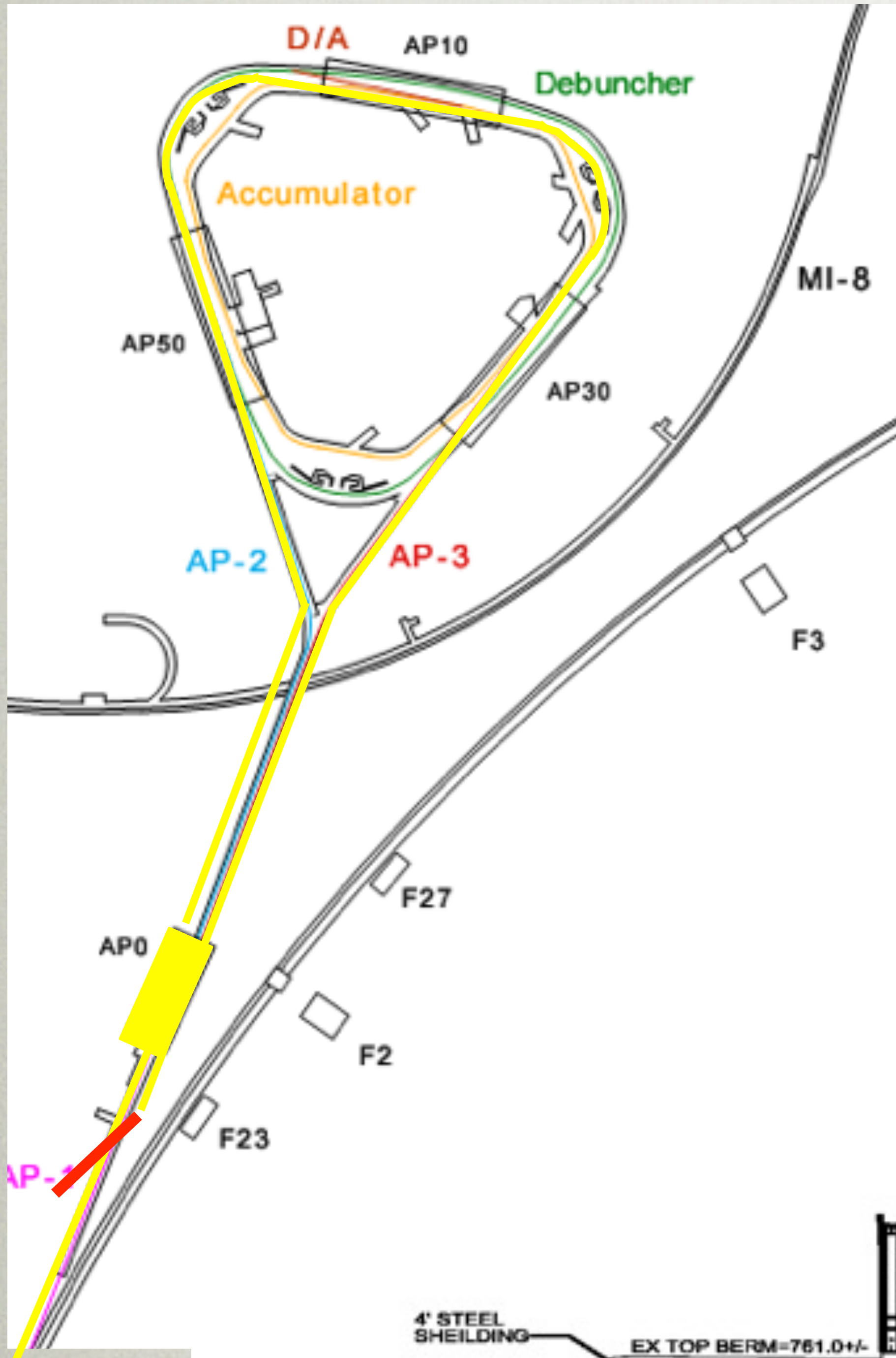


(J. Johnstone)

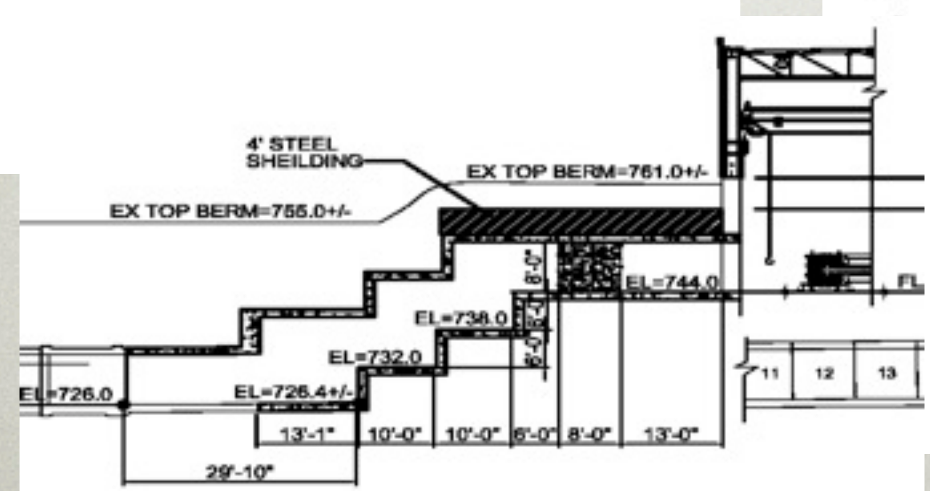
- Critical to the experiment is an 800 m or longer decay line ($\pi^+ \rightarrow \mu^+$)
  - much longer than BNL decay line, providing much purer muon beam and much reduced pion backgrounds
  - Plan to use AP2 --> Debuncher --> AP3
  - New connection DEB-->AP3
  - Denser quad spacing in AP2/AP3

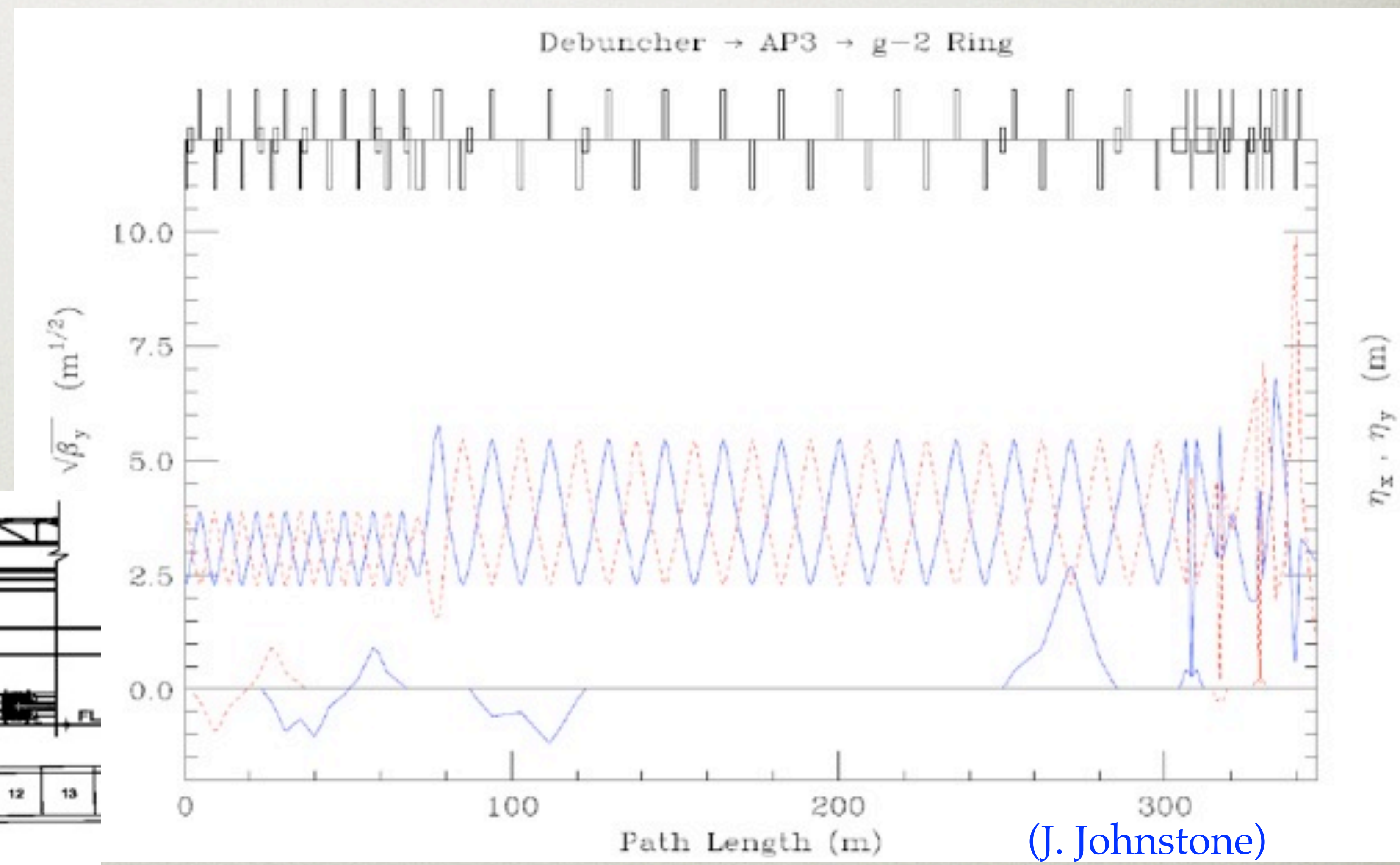


FNAL Plan--New tunnel to surface building



- Need to bring beam up to surface building
- First-order solution can be achieved
  - Horizontal and vertical bends keep the dispersion controlled
  - Match final optics into ring





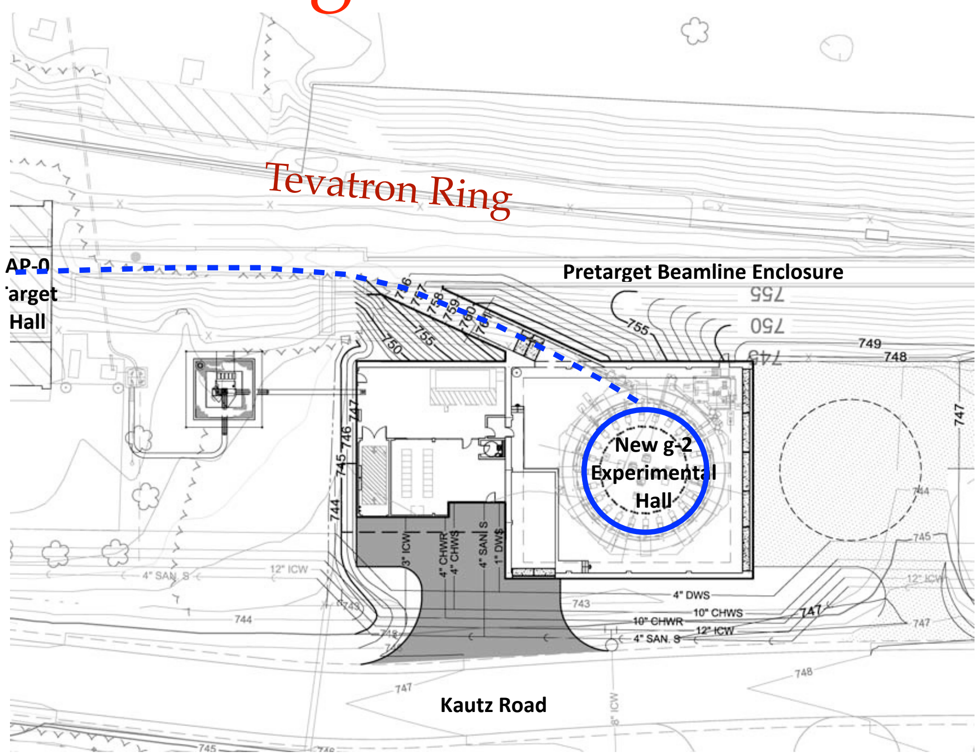
(J. Johnstone)

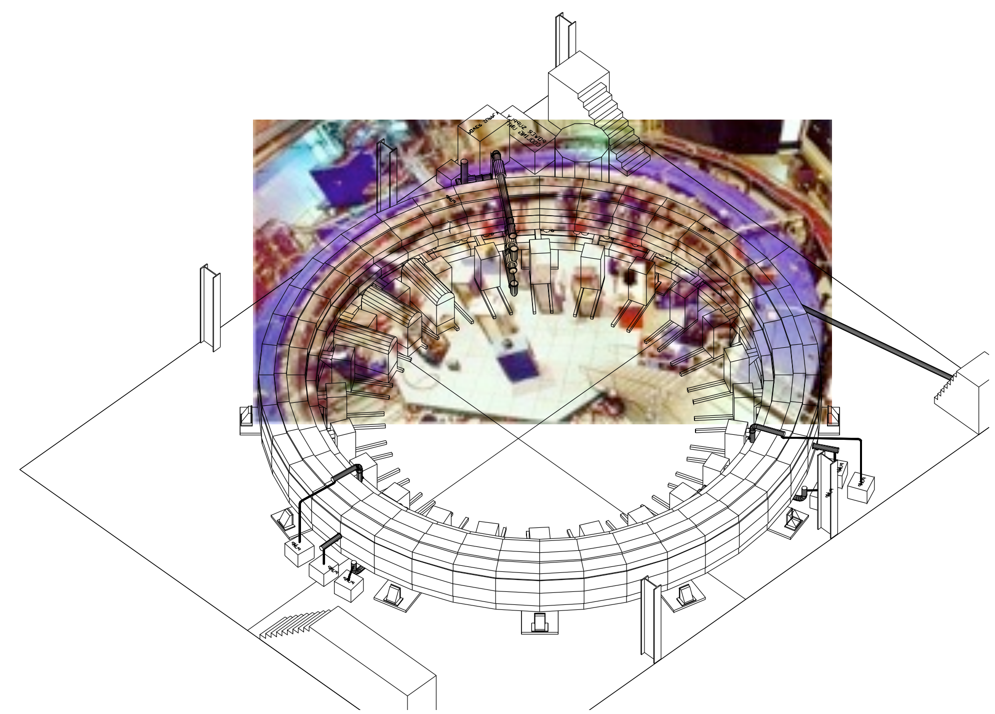
Accelerator Summary

- In NOvA era, have cycles available to run 8 GeV program from Fermilab Booster which can serve microBooNE, g-2, and Mu2e
- g-2 operates on a Booster cycle time, as does microBooNE; no physical interference, thus can run together -- Program Planning decides sharing of Booster cycles
- g-2 can start taking data 1-2 years before Mu2e; if necessary the two can operate in a "leap-frog" fashion; each takes several weeks/months of running; will take only days or weeks (<4) to switch between them (not months)
- two independent teams have analyzed the accelerator portion of the g-2 proposal, its feasibility and cost estimate -- the estimated costs agreed to within 10%
- strong accelerator team has gathered to put forth viable path for g-2 at Fermilab

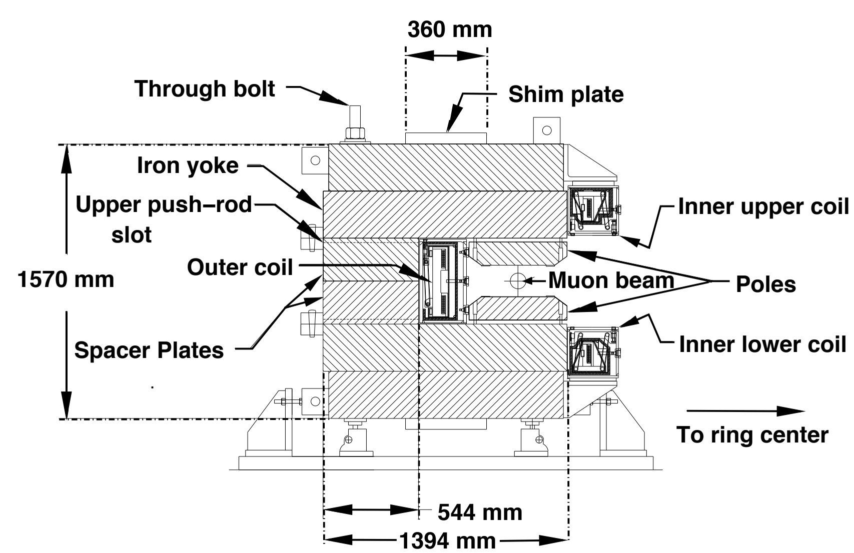
g-2 Experiment Building

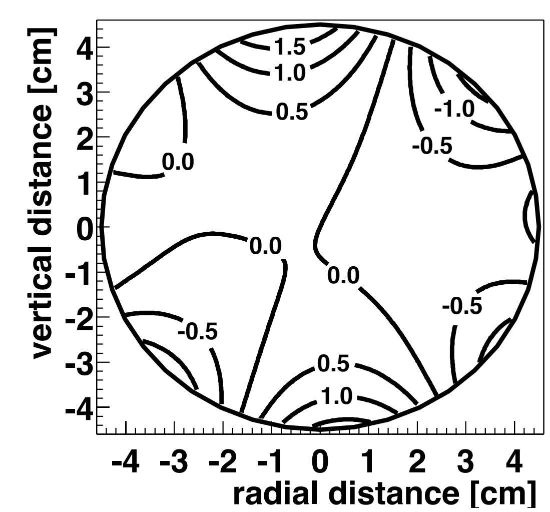
proposed siting:





- New building
- New beam line from AP0 target hall
- E821 magnet, etc.

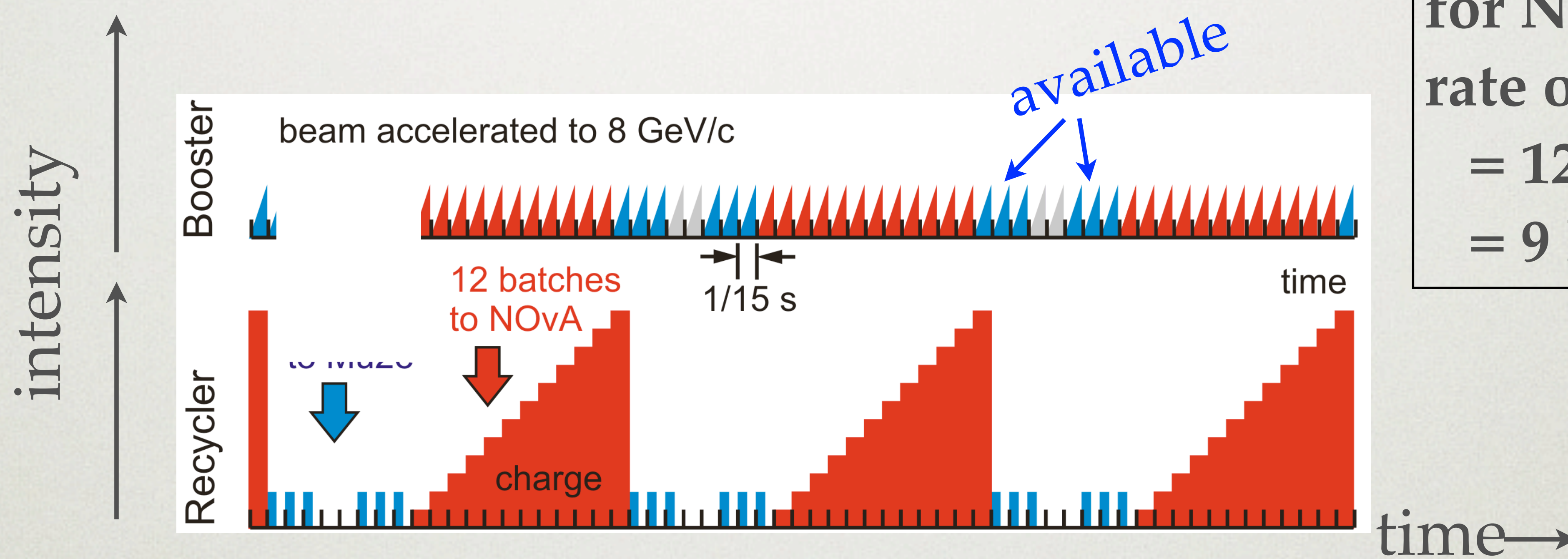




Back-Ups

NuMI/NOvA, after Run II

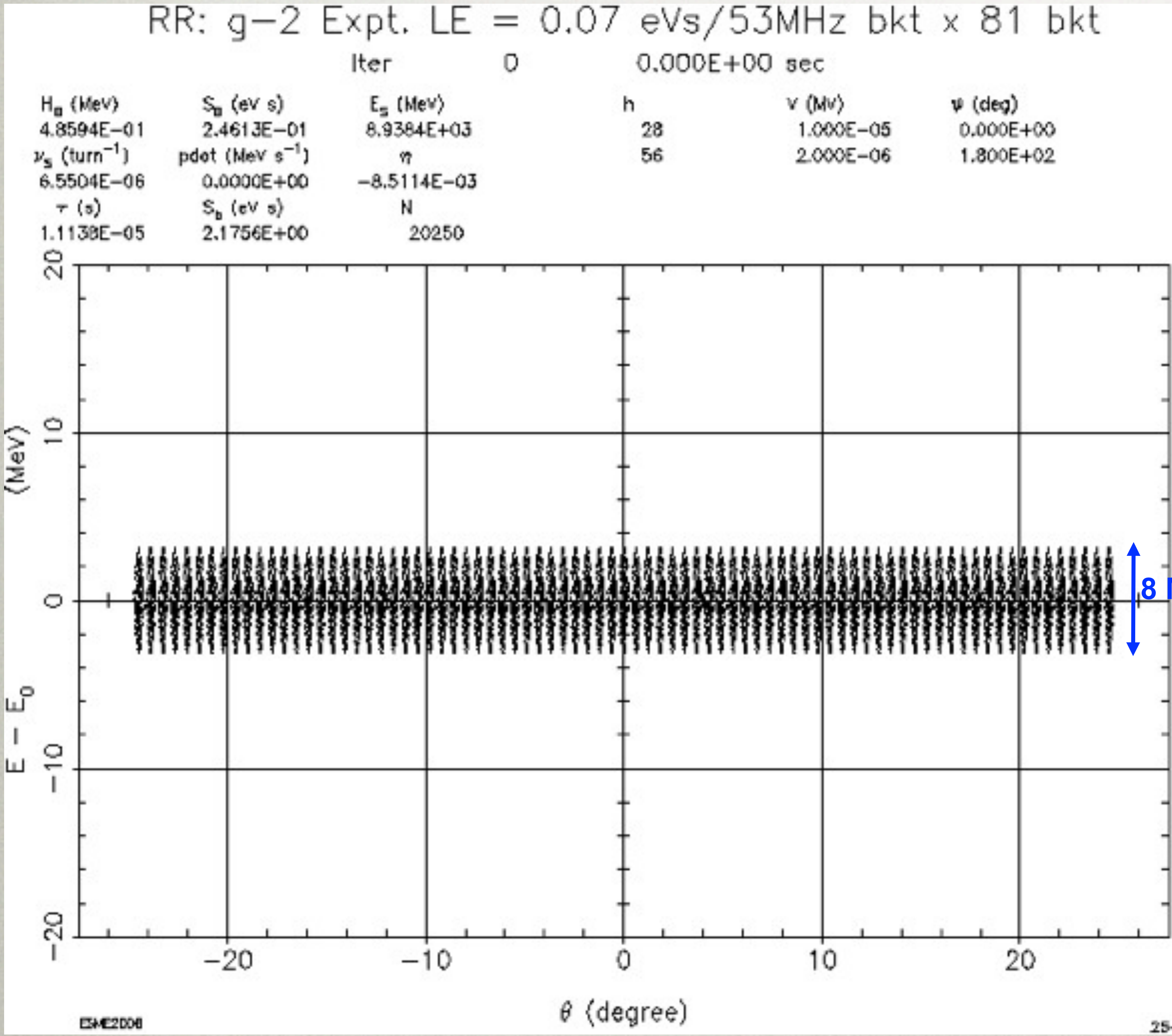
- NOvA project and associated accelerator upgrades anticipate using 12 Booster cycles per 1.333 s MI cycle



for NOvA, ave rate of BOO
$= 12/20*15$ Hz
$= 9$ Hz

- Thus, of the 20 15-Hz Booster cycles per NOvA cycle, leaves up to 8 Booster cycles for "other program(s)"
- Both Mu2e and New g-2 propose using 6 of these cycles
  - average pulse rate would be 4.5 Hz, at 4 Tp/pulse --> 18 Tp/s

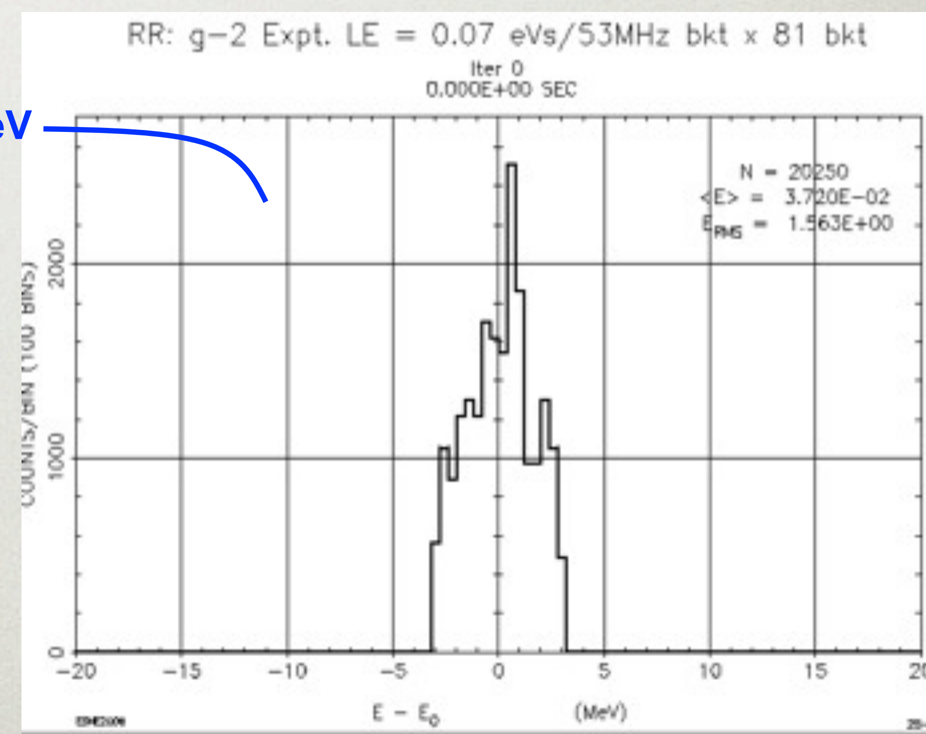
Simulations*



Broadband: 4 kV

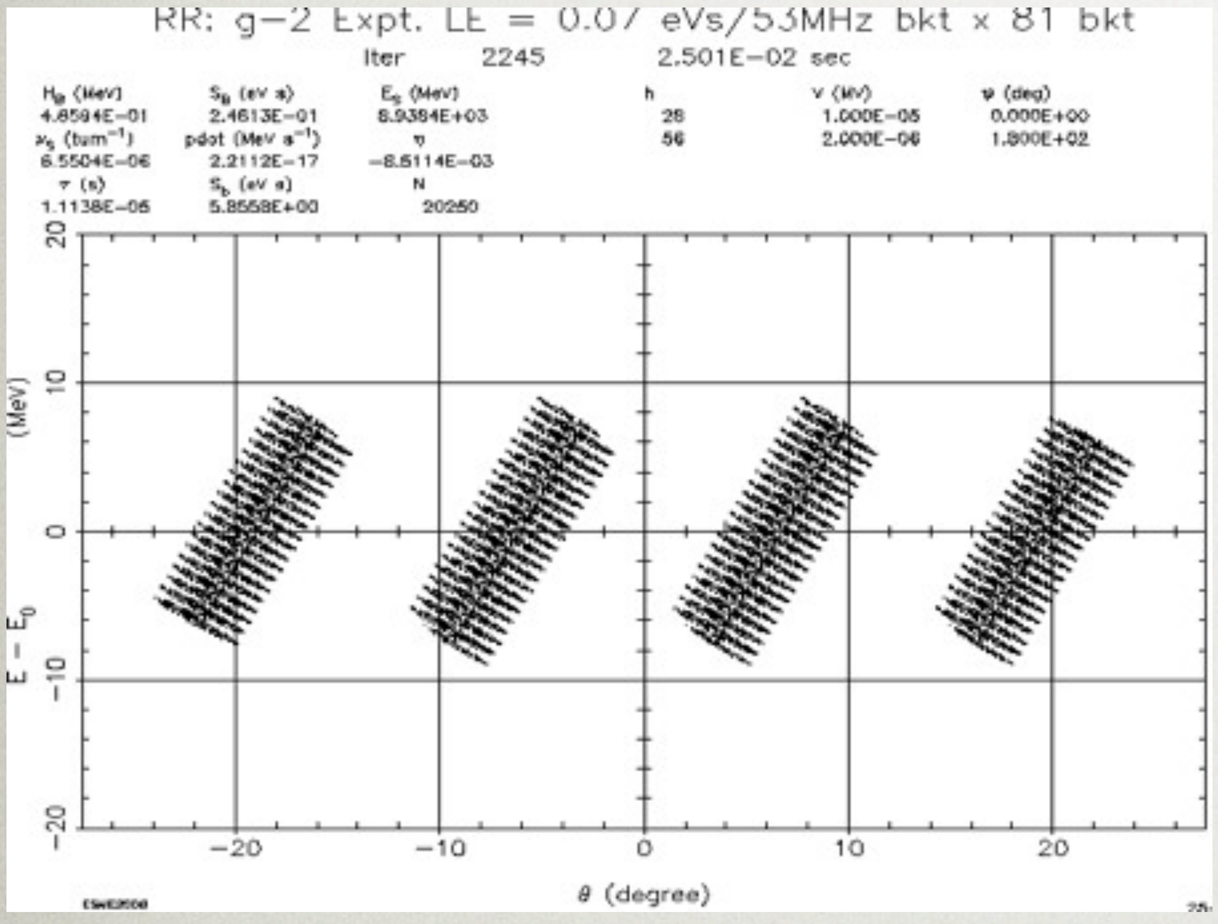
2.5 MHz: 80 kV

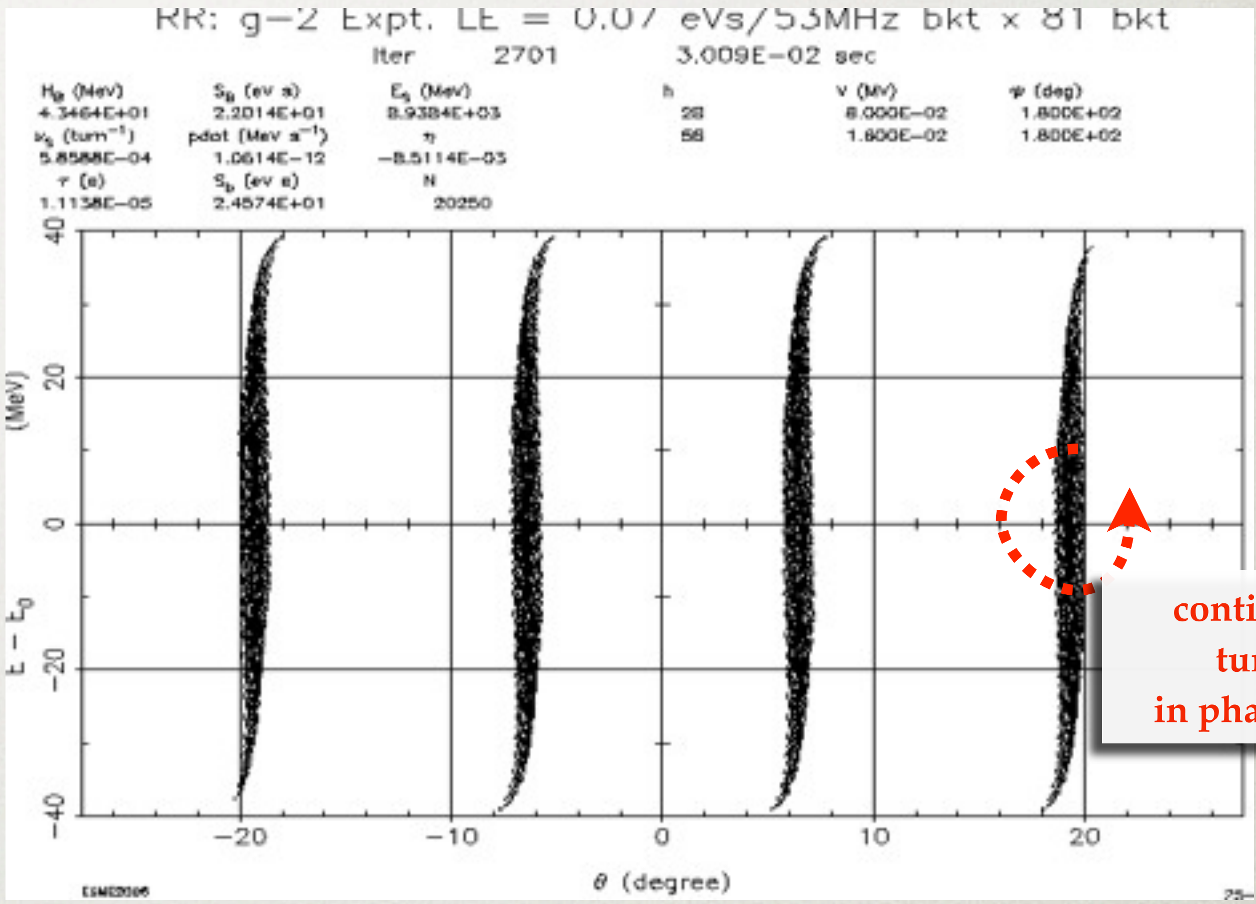
5.0 MHz: 16 kV



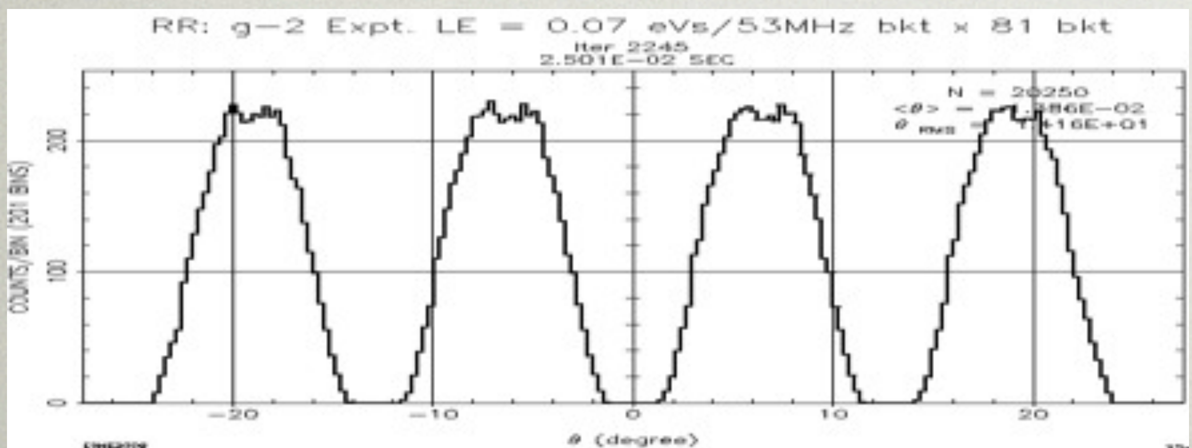
*C. Bhat and J. MacLachlan

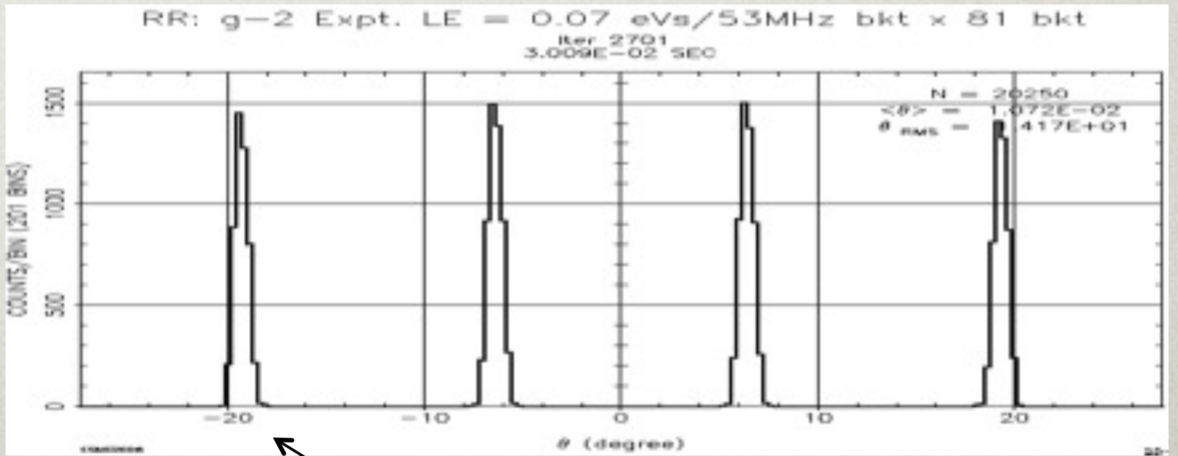
Rotate into 4 Bunches





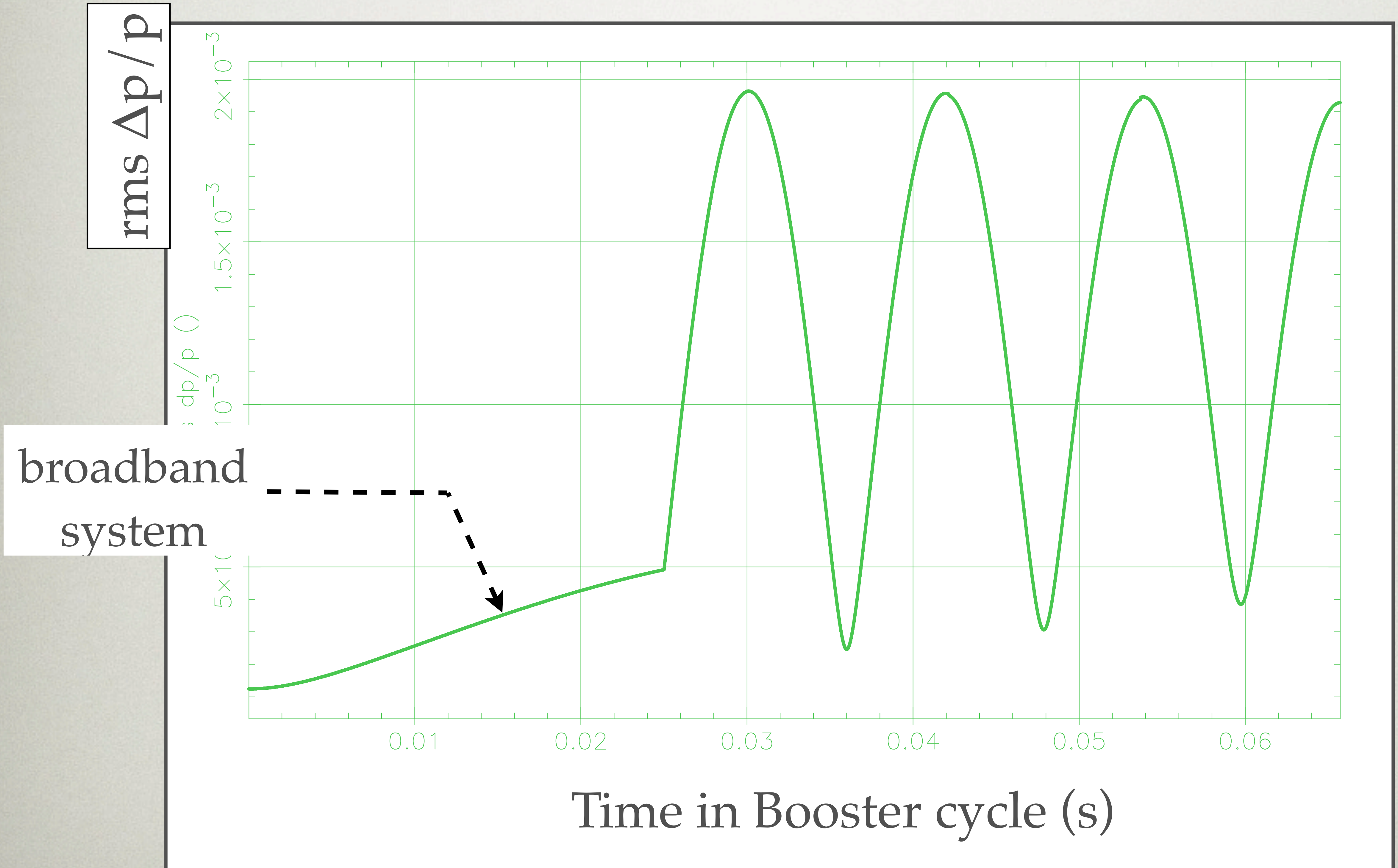
continues to tumble in phase space





Extraction of the 1st Bunch

Momentum Spread vs. Time



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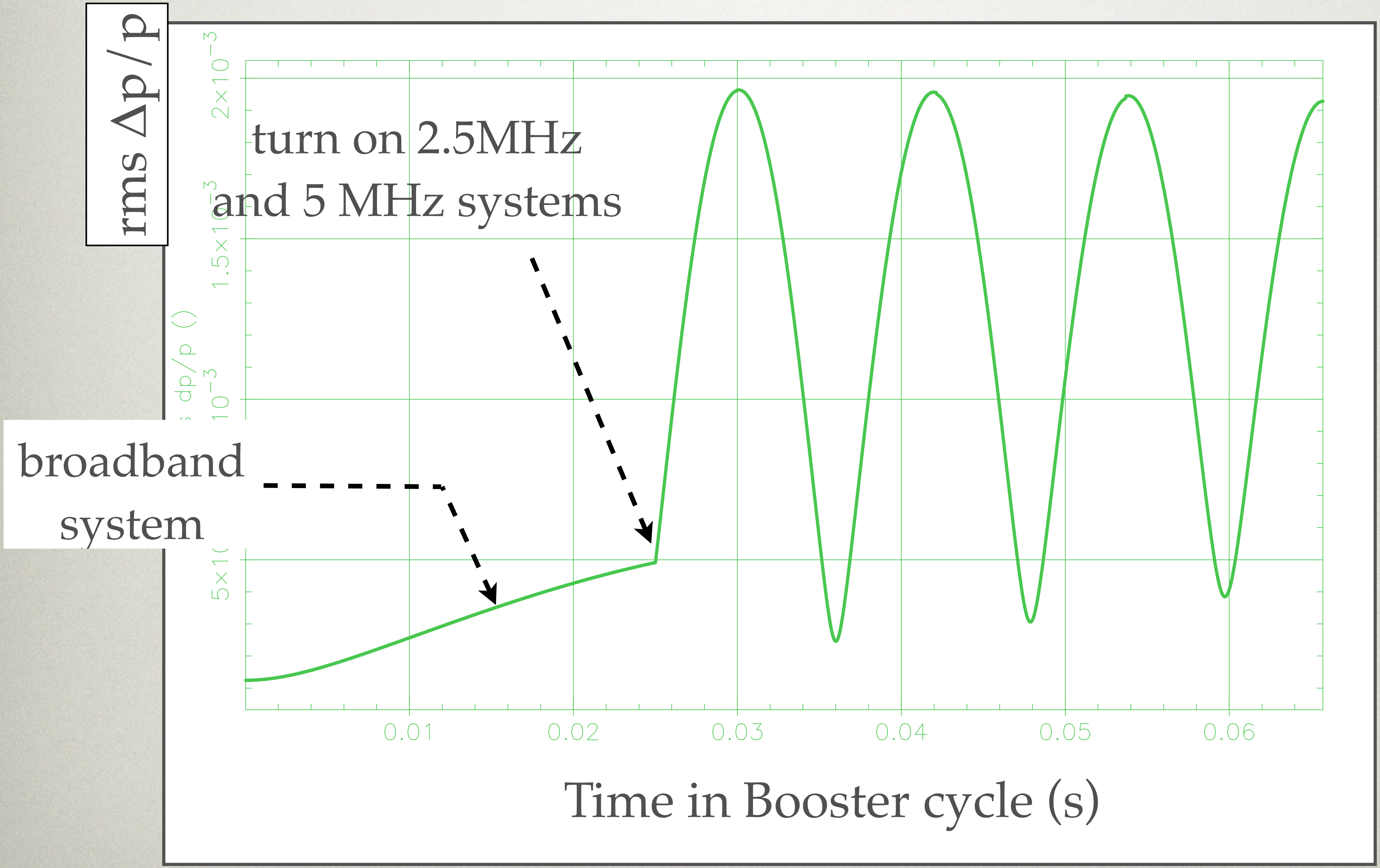

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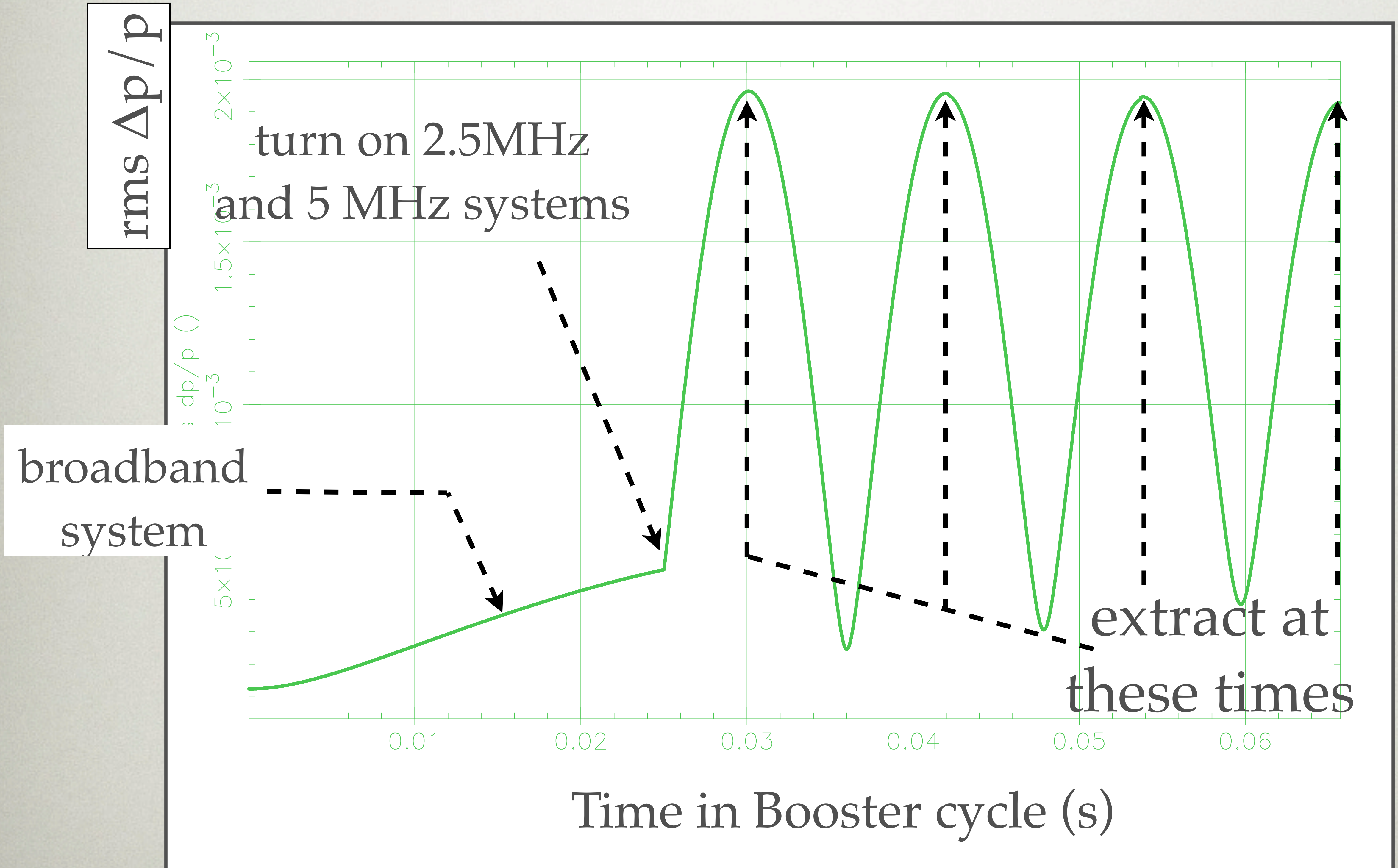

A Possible Alternative Configuration

- Direct Feed from Booster for Mu2e; g-2 still fed from Recycler
- Multiple turns in the storage rings provide long pion decay path, very high muon beam purity
- Beam for both experiments circulates in same direction in rings -- easier to switch running configuration
- Can share much of external beam line

J. Morgan, DVM, et al.

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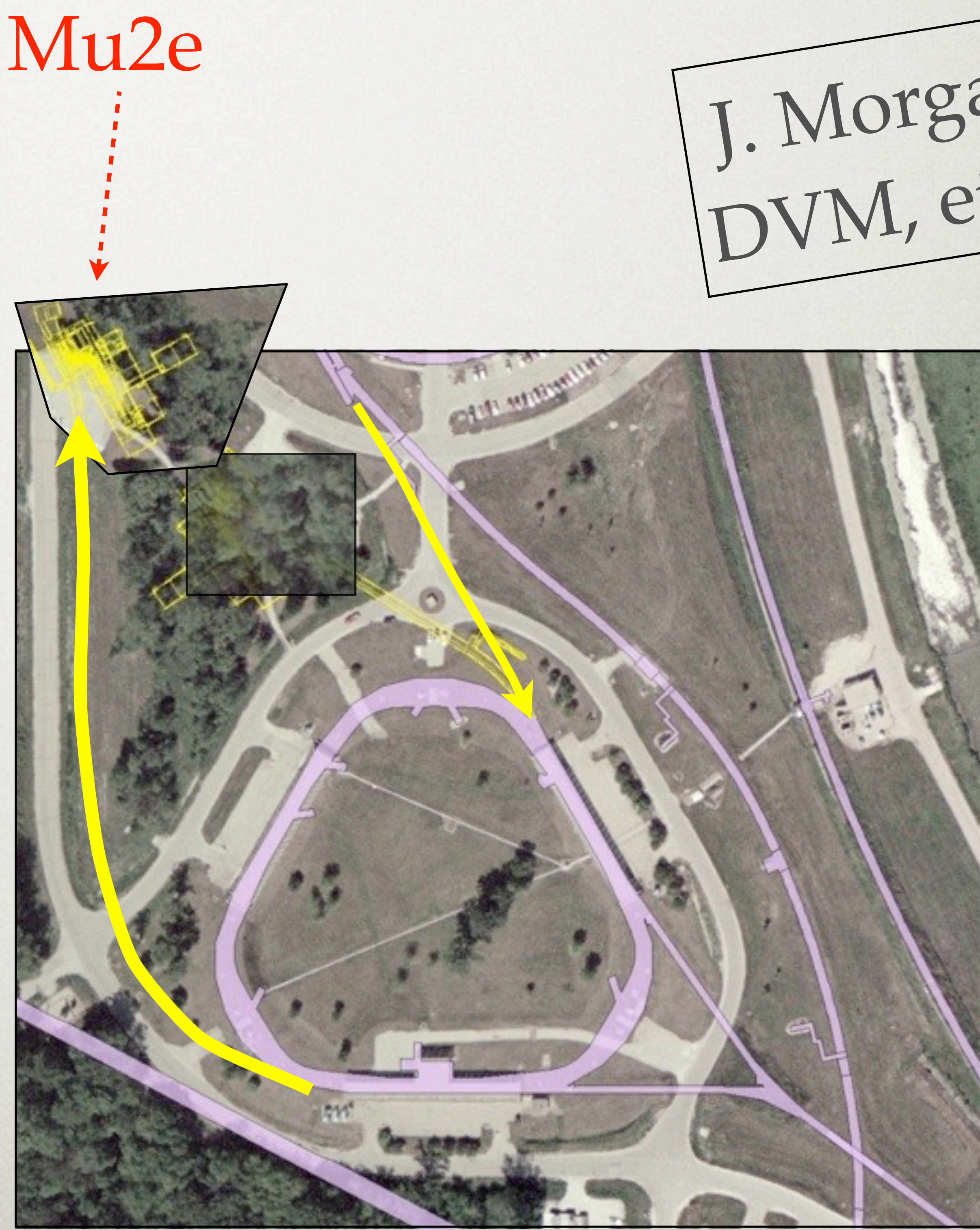

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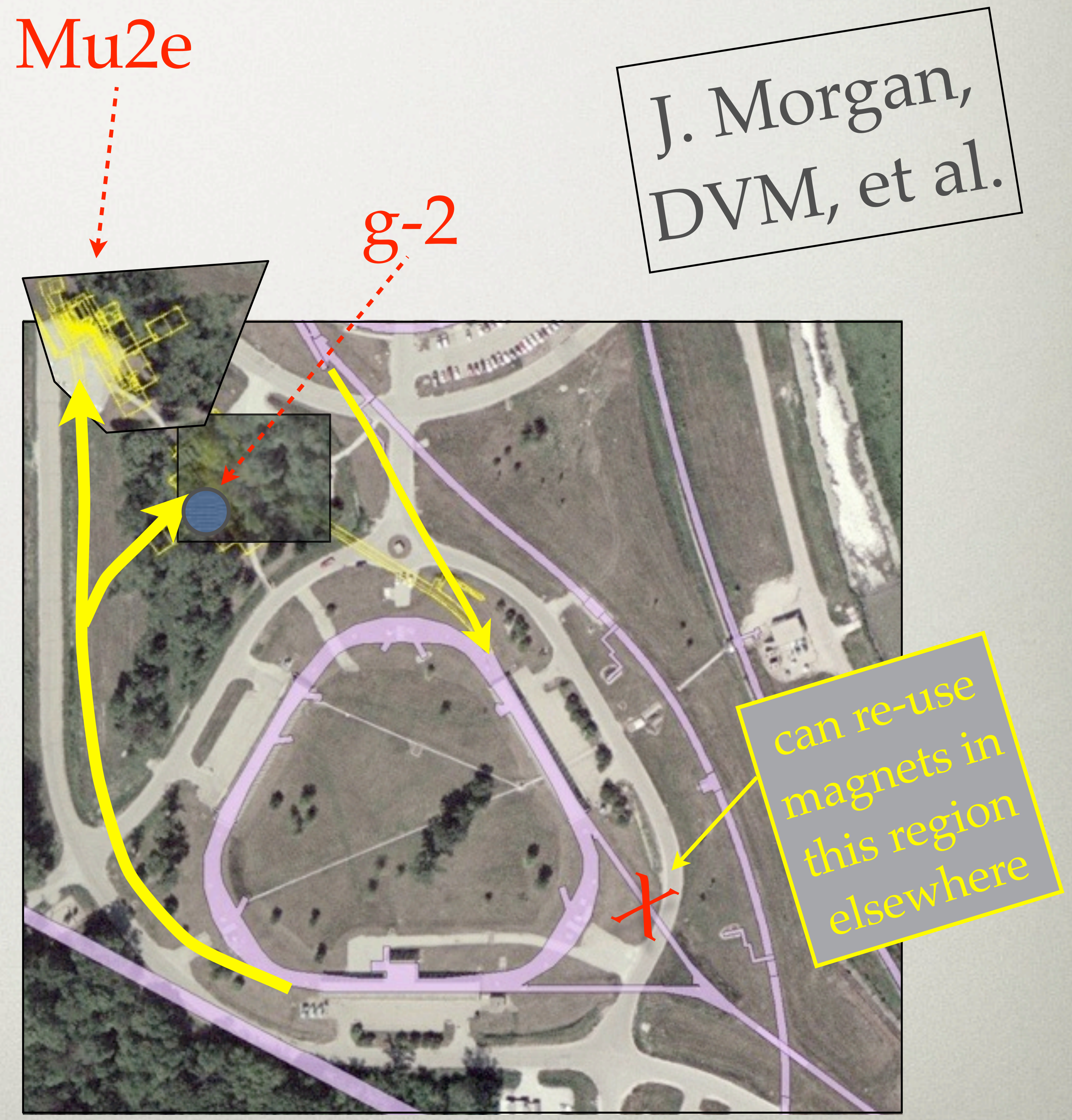

Some References

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